Quarterly Report – Public Page

Date of Report: *5th Quarterly Report – December 31, 2022*

Contract Number: *693JK3211RA0001*
Prepared for: *DOT PHMSA*
Project Title: ***Using Alternative-Steel and Composite Material in Gas and Hazardous Liquid Pipeline Systems***

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For quarterly period ending: *December 31, 2022*

1: Work Performed During this Quarterly Period

<u>Task 2 – Evaluate Material Properties and Testing Procedures</u>:

Key work activities in this task are: Identification of required material properties and setting testing procedures. Work in this quarter included:

- Completed material properties and testing requirements. This work is in Task 2 work and the report is attached in this quarterly. The report started in the 3rd quarter and is finalized this quarter.
- Negotiated the commitment of 4 composite pipes manufacturers. Working on negotiating the NDA with the 5th manufacturer.

<u>Task 3: Design for Maximum Allowable Operating Pressure:</u>

- Reviewed standards to identify gaps in the existing qualification procedures for determining maximum allowable operating pressure in composite pipes.
- Developed a complementary testing procedure based on identified gaps. Discussed the procedure with the TAP members.

Work of Tasks 2 and 3 continues. Task 2 Summary Report: *Material Properties and Testing Requirements* is attached in this quarterly.

2: Items Not Completed During this Quarterly Period:

Task 3 of the testing is not complete yet. The sub-contractor (C-FER) is planning on performing these tests once the composite samples are delivered.

3: Project Technical Status

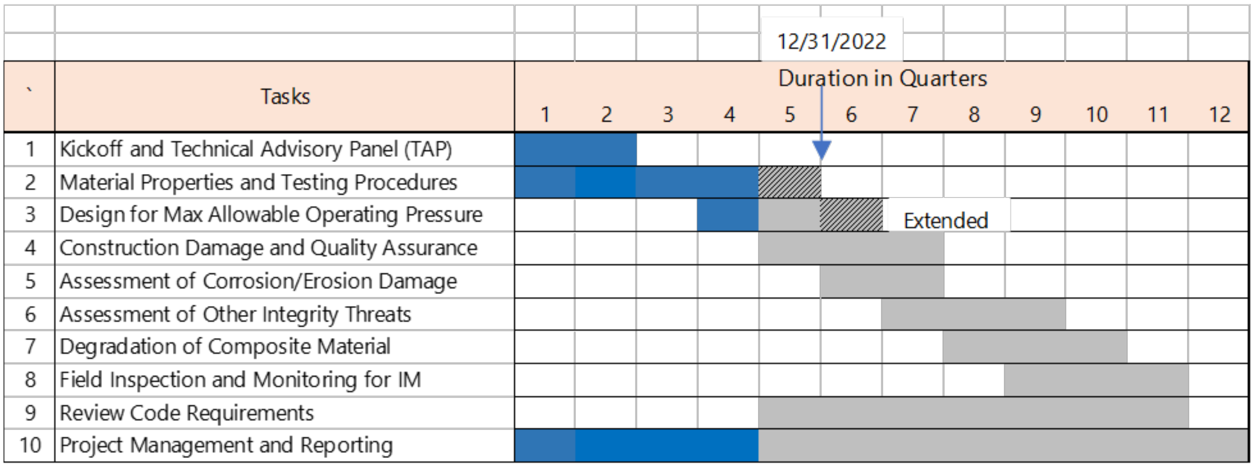
The report, in the Attachment, covers the following:

- Task 2 Report: *Material Properties and Testing Requirements*

4: Project Schedule

Figure 1 shows the project schedule and progress as of the end of this quarter. Task-3 work is extended to the following quarter.

Figure 1- Project time schedule



TASK 2 - MATERIAL PROPERTIES AND TESTING PROCEDURES FOR COMPOSITE PIPES

1. INTRODUCTION

1.1 Background

GTI Energy has contracted C-FER Technologies (1999) Inc. (“C-FER”) to perform the work set forth in the Agreement for Services (Agreement No. S1111/GTI Project No. 23058), dated January 12, 2022. As defined in Appendix A of the Agreement (i.e., Task 2 and Task 3), C-FER was contracted to conduct a review of composite material properties and assess the suitability of GTI Energy’s qualification procedures – the culmination of this work is presented herein (collectively referred to as the “Investigation”).

The Investigation aimed to identify and evaluate important considerations within the current body of publicly available standards and recommended practices (i.e., that are used to qualify composite pipes for use in high-pressure oil and gas applications), with the key objective of defining appropriate product validation testing to address the identified gaps through a series of full-scale laboratory tests.

This document summarizes the proposed testing procedures and outlines the respective test matrix.

1.2 Testing Overview

A comprehensive literature review, as well as a manufacturers’ survey (the “Market Survey”), identified publicly available standards currently used to qualify composite pipelines for transmission and high-pressure distribution of oil and gas products. Note that the proposed material evaluation tests in this document are not meant to replace the material qualification tests prescribed in existing standards, including API RP 15S (1), but rather they are intended to complement them with extended standardized tests for regulatory evaluation. The details of the literature review, Market Survey, and prioritization exercise are summarized in Ohaeri et al. (2). The following test types were the focus of the material testing portion of the Investigation:

- Impact Resistance (i.e., to equipment damage);
- Hydrostatic Pressure; and
- Bending (i.e., at the proximity of a joint).

To provide a basis for the aforementioned tests, a summary is provided in Sections 2 – 5.

2. DIMENSIONS OF TEST SPECIMEN

Based on discussions with the manufacturers and the availability of testing equipment, pipes with a nominal diameter of 6 in (152.4 mm) will be tested. To compensate for end effects at the joints, a longer specimen of approximately 12 times (12×) the pipe inside diameter (ID), corresponding to a specimen length of 72 in (1828.8 mm), is preferred. The specimen dimensions for all test procedures are shown in Figure 2.1.

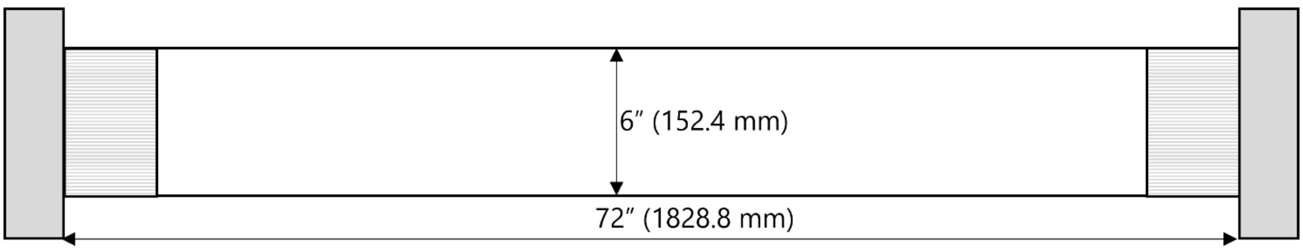


Figure 2.1 Schematic Representation of Impact-test Specimen

Two impact-test specimens are expected to be supplied by each manufacturer, retrofitted with pre-attached end fixtures, to allow for ease of connection to C-FER's test frame. The ends of the impact-test specimens should be sealed with the appropriate blind flanges, which contain a 0.375 in (9.5 mm) threaded hole drilled at both ends for pressurization and venting. The blind flange shall withstand the maximum internal pressure of the pipe without allowing failure at the connections.

3. IMPACT RESISTANCE TEST

3.1 Test Overview

The objectives of this test are to: a) evaluate the behavior of composite pipes (i.e., when subjected to loads from equipment contact during third-party excavation, and in the absence of the host steel pipe); and, b) simultaneously apply different loading scenarios, as suggested in Section A841 of ASME B31.8-2020 (3), Sections 4.1.4 – 4.1.5 of API RP 1111 (4), and Annex O, Table O.1 of CSA Z662:19 (5).

Section 5.7.3 of API RP 15S (1) recommends that the impact energy resistance of composite pipes be determined using the falling-weight Tup-B approach, specified in ASTM D2444-21 (6). However, the magnitude of the impact load specified in ASTM D2444-21 (6) is not representative of all possible situations that may occur during pipeline operations and does not consider the more severe scenarios that may arise due to equipment impact on onshore pipelines. For instance, an excavator weighing 998 kg (2200 lbs) impacts a pipeline with a force of approximately 36 Kips (5). In addition, the current qualification approach considers the internal pressure and the impact load separately. The inherent anisotropy of composite material properties reinforce the need for a better understanding of the effect of the interaction between different loads, especially when the composite pipes are directly buried in the ground without a host steel pipe.

Without reliable information describing the mechanical impact damage that a composite pipe can withstand, it will be challenging to defensibly demonstrate when additional mitigation (i.e., preventative, and protective) measures are required (e.g., increased burial depth, installing a painted concrete slab, installing additional right-of-way signage).

3.2 Test Procedure

The impact resistance test will consider combined loading conditions (i.e., internal pressure, and equipment impact), as well as the effect of temperature. ASME B31.3 (7) defines the required conditions for including impact testing in the qualification process of steel pipes. The conditions are based on the design minimum temperature given by the manufacturer, and the nominal wall thickness and hardness curves. While it is difficult to define unified hardness curves for composite pipes, their impact performance should be assessed at different temperatures.

During testing, mechanical damage will be simulated by externally indenting composite pipe specimens at ambient temperatures, under representative operating internal pressures. Pressures are chosen to reflect a realistic situation where a pipe in service is subjected to external impact forces. Each specimen will be indented at C-FER's main laboratory, located at 200 Karl Clark Road, Edmonton, Alberta, using our Universal Testing System (UTS); which is a servo-hydraulic load frame of 3.3 kips capacity (refer to Appendix A, p. 14).

3.2.1 Specimen Preparation

The composite pipe manufacturers shall arrange to ship the test specimens to C-FER's laboratory, located at 3712 Roper Road NW, Edmonton, Alberta.

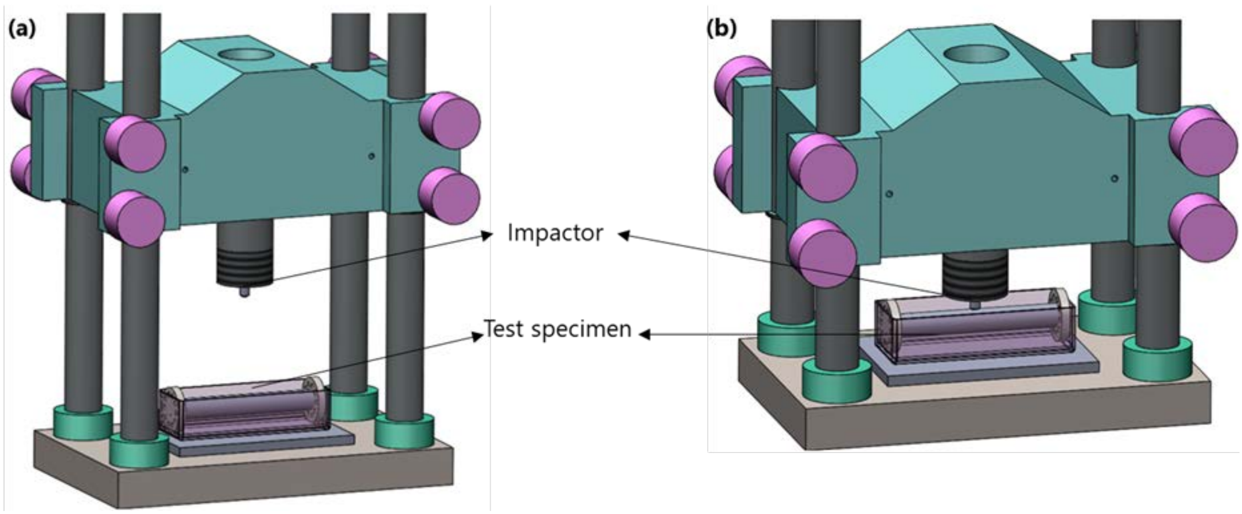
In the laboratory, the specimens will be assessed via the following two steps:

1. Visually inspect the specimens to ensure there are no manufacturing defects.
2. Measure the dimensions to accurately determine the wall thickness, outer diameter (OD), and length of the specimens.

3.2.2 Test Setup

The impact resistance test setup will consist of the following steps:

1. Position each specimen horizontally in the UTS and firmly secure it to the base, as illustrated in Figure 3.1.
2. Pressurize each specimen with water to its operating pressure.
3. Place supports around the specimen to mimic a buried condition and to restrict the specimen from moving during testing.
4. Install custom-built containment to avoid flooding during or after testing.



(a) **(b)**

Figure 3.1 Schematic of Impact Resistance Test Setup with Retracted Impactor (a) and Extended Impactor (b)

3.2.3 Testing and Decommissioning

Impact resistance testing and decommissioning will consist of the following steps:

1. Impact specimens using a 2 in (51 mm) steel ball. The impactor will mimic the nose radius for a Tup-B impact tester, according to ASTM D2444-21 (6).
2. Set the actuator controls to apply gradual and continuously increasing load over time to its maximum capacity or until rupture/leakage occurs.
3. Record the dent depth and inspect failed specimens to understand the mode of failure prior to decommissioning the test setup.
4. Determine a failure criterion, as defined for steel pipes. For instance, the European Pipeline Research Group (EPRG) established that when the ratio between the dent depth and the diameter of the pipes is less than 7 percent and the pipeline is operated at stress level below 72 percent specified minimum yield strength (SMYS), failure will not occur (8).

4. HYDROSTATIC PRESSURE TEST

4.1 Determination of Hydrostatic Design Basis from Pressure Test

Determining the hydrostatic design basis (HDB) for composite pipes and adjoining fittings is complex due to varying product characteristics across different manufacturers. To properly evaluate the long-term hydrostatic strength of composite pipes, it is important to understand the mechanical properties of their constituents in the case of multi-layered composites containing non-polymeric materials (9). API RP 15S (1) recommends a separate approach for determining pressure rating in metal- and non-metal-reinforced composite pipes. The conventional long-term hydrostatic pressure test is recommended for non-metal reinforced composite pipes, while short-term hydrostatic pressure test is required for metal reinforced composite pipes.

4.1.1 Conventional Long-term Hydrostatic Pressure Test

The long-term hydrostatic test is largely performed according to guidelines specified in ASTM D2992-18 (10). It involves subjecting composite pipes to an internal hydrostatic creep rupture tests and the pressurized pipes are tested up to 10,000 h at the prescribed pressures until creep failure occurs.

Two methods are used to obtain the HDB of the fiber-reinforced composite pipes (11, 12, 13), namely: a) Procedure A, which requires cyclic loading; and 2) Procedure B, which requires continuous (static) loading. Irrespective of the test procedure adopted, the appropriate service (design) factor must be used to determine the allowable stresses and design limits for composite pipe. For example, ASME NM.2 (14) recommends a design factor of not more than 1 when Procedure A is used, while a design factor not exceeding 0.5 is specified for Procedure B. It is important to understand that both standards (i.e., ASTM D2992-18 (10) and ASME NM.2 (14)) refer to composite pipes that are made of glass-fiber-reinforced thermosetting resin. The composite pipe products that are the focus of this project are mostly reinforced thermoplastic composites.

API RP 15S (1) offers guidance for qualifying spoolable, reinforced plastic pipe and recommended the use of Procedure B for non-metal-reinforced products in Section 5.3.1. The loading condition must be static for Procedure B to be applied on these types of pipes. If cyclic loading is a concern, Annex G of API RP 15S (1) describes the qualification requirements for evaluating pressure fluctuations based on Procedure A. Note that typical pipeline operations involve some degree of pressure cycling (e.g., pressure pulsations, pump on/off cycles, pump jack strokes), and therefore, are believed to operate outside the baseline conditions identified in API RP 15S (1). However, the current test program is a preliminary demonstration aimed at illustrating/evaluating the potential for additional or supplementary test procedures to complement those already in use; therefore, consideration will not be given to cyclic loading conditions. Instead, the focus here will be to perform the basic quasi-static pressure test according to Procedure B.

In evaluating the need for alternative procedures to complement existing approaches for determining HBD, the following notable considerations of Procedure B have been identified (15):

- Operating temperature requirements may vary depending on the type of composite materials; therefore, revised testing temperature will be required for each product;
- Tests results cannot be scaled for different pipe sizes and geometries; therefore, any change to a pipe's geometry or composition warrants re-qualification following the ASTM D2992-18 (10) process;
- It is assumed that regression analysis can be used for data extrapolation;
- It is assumed that the pipe material consists of a single homogeneous layer thermoplastic. This could lead to some inaccuracies when considering complex multi-layered composite pipes (16);
- The pipe material is assumed to be thin walled so that hoop stress can be determined based on the membrane theory of thin-walled tubes; and
- The procedure is time consuming and expensive.

4.1.2 Modified Short-term Hydrostatic Test

Much research has been undertaken to find possible correlation between short- and long-term hydrostatic burst tests for composite pipes. Finite element analysis (FEA) was used to determine the residual strength of composite pipes based on creep phenomena, stress analysis, and failure behaviour (15, 17). These studies show some similarities between the short-term pressure tests with long-term performance of fiber-reinforced composite pipes. Also, they observed reasonable correlation between the results of the FEA and experimental data.

Among several techniques that have been explored to provide alternative solution for predicting long-term hydrostatic pressure, one option seems particularly promising. It entails analyzing the stress-strain pattern with the intention of identifying the onset of non-linearities in the elastic behaviour of pressurized composite pipe through a combination of strain to failure and ultimate elastic wall stress (UEWS). The UEWS is defined as the pressure at which non-linear stress-strain response begins to manifest. This behavior has been observed in short-term cyclic pressure tests where the intention was to identify the hoop stress (i.e., pressure)-strain value above which the rate of damage progression becomes a concern for long-term failure. This technique was applied for different pipe materials, including fiberglass-reinforced thermosets (18, 19) and glass/epoxy composite pipes (20, 21). So far, no significant attention has been paid to applying this method during quasi-static burst test. Also, most of the studies reported in the literature were conducted on thermoset-based fiberglass composite pipes. It is important to evaluate this technique on thermoplastic-based fiberglass composite pipes.

The major argument in favour of the regression-based method is that it offers a statistical approach for obtaining the HDB. This may be considered preferable for design, barring the time-related limitations that are involved in performing long-term tests. A summary of the unique distinctions and similarities between the UEWS approach and the conventional regression method is presented in Table 4.1.

Metric	Regression Method (as per ASTM D2992-18 (10))	UEWS Method
Effort/convenience (i.e., time + cost)	This test method is very time consuming with a testing requirement exceeding 10,000 h and may last up to two years before HDB is determined. Often it results in very conservative estimates of long-term pipe behaviour, which may be unacceptable for such an expensive program. The test set-up is fixed in place for a long time.	This test method is less time consuming, and the results can be obtained within a day of testing.
Sensitivity to changes in material composition	This test method is sensitive to changes in material properties and pipe manufacturing techniques and requires a reconfirmation test (for up to 1,000 h) according to ASTM D2992-18 (10) that will result in yes or no results.	This test method is also sensitive to changes in the material properties and pipe manufacturing methods. However, the UEWS provides an exact value for HDB.
Chemical compatibility	Both test methods are not useful for assessing long-term degradation of composite pipes exposed to different environmental conditions.	

Table 4.1 Summary of Differences Between the Conventional Regression-based Approach and the UEWS Test Technique for Qualifying Composite Pipes (18)

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